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A Comparative Study of Two Biological Processes for Odour Treatment: Biofiltration *vs.* Activated Sludge Diffusion

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The odorant removal efficiency (RE) and process stability of a conventional biofilter (BF) and an activated sludge diffusion system (AS) were comparatively evaluated at different empty bed residence times (EBRT = 94, 74, 55, 48 and 32 s). A synthetic odorous emission of H_2S, butanone and toluene at concentrations ranging from 25 to 40 mg m^{-3}, 4.3 to 6.3 mg m^{-3} and 0.4 to 0.6 mg m^{-3}, respectively, was fed to the reactors during 120 days. Alpha-pinene was then added to the inlet odorous stream at concentrations of 0.12-0.15 mg m^{-3} when the process was operated at 32 s of EBRT. H_2S was completely removed while butanone and toluene REs always exceeded 95% in both bioreactors regardless of the EBRT. However, the REs achieved for alpha-pinene were always lower than 10%. Finally, it must noticed that the AS system collapsed at day 91 due to biomass aggregation. Daily supplementation of 2 g glucose d^{-1} and AS operation at 25 d of sludge retention time restored process performance in this system.

1. Introduction

In the past few decades, odorous emissions have become one of the main challenges for Wastewater Treatment Plants (WWTPs) due to the increasing number of malodours-related public complaints and to the enforcement of more stringent environmental regulations (Stuetz et al. 2001). The strategic relevance of the problem initially triggered the implementation of physical-chemical off-gas abatement technologies such as chemical scrubbers, activated carbon filtration, incineration and ozonization technologies, etc. However, WWTP operators became rapidly aware of the merits of biological treatment processes such as bioscrubbing, biotrickling filters and biofiltration: high efficiency, low operation costs and absence of hazardous end-products (only CO_2, H_2O and biomass are produced) (Burgess et al. 2001). Biofiltration is indisputably the most commonly employed biotechnology for odour treatment in WWTPs. Despite their cost-effectiveness, the widespread implementation of biofilters is often restricted by their large footprint (high empty bed residence times and low packed

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media heights in order to minimize pressure drops) and by the compaction of packing media. In addition, the technical difficulties to carefully control pH and moisture content in the packed bed (basic requirements to maintain a high microbial activity), and to avoid the accumulation of inhibitory by-products can also limit biofilter performance (Delhoménie and Heitz, 2005).

In this context, activated sludge diffusion systems (AS) represent a cost-effective alternative to media-based bioreactors for odour treatment. In AS systems, malodorous emissions are directly sparged into the aeration tank together with the air necessary to satisfy the biological oxygen demand of the wastewater and subsequently degraded by the activated sludge community (Burgess et al. 2001; Barbosa et al. 2002). AS systems possess all merits of their biological counterparts (environmental friendliness, low operation cost), while overcoming most of their major limitations (packing media compaction, pH control, accumulation of toxic metabolites in biofiltration, etc.). In addition, the use of the existing aeration tanks as odour-abatement unit renders them economically attractive in plants where space availability constitutes the main limitation and where wastewater treatment oxygenation is performed via air diffusion. Despite the high odour and H_2S REs reported, the major limitation of AS systems is the lack of data concerning their performance during the treatment of hydrophobic VOCs odorants (Bowker 2000).

This work was conducted to systematically compare the performance of a conventional biofilter (BF) and an AS system for the treatment of a model WWTP malodorous emission containing four representative odorous compounds with a large range of hydrophobicities: H_2S, butanone, toluene, and alpha-pinene (Zarra et al. 2008).

2. Materials and methods

The experimental pilot plant was composed of two jacketed bioreactors, a BF and an AS diffusion system, operated in parallel. Both bioreactors (120 cm high x 10 cm internal diameter columns) were made of clear PVC with a working volume of 8.5 litres and operated at 20 ºC. The BF was packed with 8.5 L of a mixture of compost and perlite (75%/25% v/v) while the AS was initially filled with 7.5 L of MSM (Muñoz et al. 2008).

The odorous stream was prepared by mixing rather a concentrated H_2S/butanone/ toluene mixture or a concentrated H_2S/butanone/toluene/alpha-pinene mixture from a calibration bottle with a previously humidified odour-free air stream. The odorous emission was then equally split and fed to the BF from the top of the reactor and to the AS via three ceramic spargers located at the bottom of the bioreactor. Both bioreactors were initially inoculated with 1 L of concentrated (17 g DW L^{-1}) aerobic activated sludge resuspended in MSM. The systems were first operated during approx. 94 days in order to comparatively evaluate the influence of the empty bed residence time (EBRT of 94, 74, 55, and 48 s) on odorant removal efficiency using H_2S (16.9-23.8 mg m^{-3}), butanone (4.3-6.3 mg m^{-3}), and toluene (0.40-0.60 mg m^{-3}) as model odorants. During this period, the AS system was operated with no biomass purge. However, due to biomass aggregation on day 95, the sludge retention time in the AS system was set up at 25 days by daily withdrawal of 340 ml of culture broth and replacement with fresh MSM containing 2 g of glucose in order to asses the influence of an easily

biodegradable carbon source into process performance. Once a steady state was reached, the EBRT was further decreased to 32 s. At day 121, the above mentioned synthetic odorous stream was supplemented with alpha-pinene (0.12-0.15 mg m^{-3}). Each operational condition was maintained for at least 3 weeks in order to ensure stable steady states. The pH in the AS system was maintained constant at approximately 6.30 ± 0.29 and sulphate concentrations was kept below 3000 mg L^{-1}. Likewise, 250 ml of MSM were periodically irrigated from the top of the BF via a spray nozzle.

H_2S, the organic odorants and CO_2 concentration were periodically monitored at both the influent and effluent gas sampling ports. Biodegradation profiles in the BF were also determined by gaseous sampling at different heights of the BF (0, 40, 80 and 120 cm). Liquid samples were periodically withdrawn from both bioreactors.

2.1 Analytical procedures

H_2S concentration was analysed using an electrochemical sensor (Dräger X-am 5000). Butanone, toluene and α-pinene were collected in 250 ml glass bulbs and pre-concentrated by solid phase microextraction (SPME) fibres (Supelco, USA) during 10 min prior to injection in a GC-FID (Hewlett Packard HP 6890 Series, SupelcoWax 15m x 0.25mm x 0.25 µm column). Oven, injector and detector temperatures were maintained at 60°C, 280ºC and 250 ºC respectively. Helium was used as carrier gas at 2 ml min^{-1}. CO_2 concentration was measured by GC-TCD (Muñoz et al. 2008).

Sulphate concentration was determined by HPLC-IC using an IC-Pak Anion Guard – Pak Waters column and an IC-Pak Anion HC 4.6 x 150 Waters column. pH was also measured using a pH/mV/ºC meter (pH 510 Eutech Instruments, The Netherlands). Biomass and specific ATP concentration in the AS liquor were measured according to Muñoz et al. (2008). Finally, pressure drop in the biofilter was determined using a home-made differential pressure meter.

3. Results and Discussion

The results herein obtained showed the high potential of both biotechnologies to achieve high steady state removal efficiencies for H_2S, butanone and toluene even at EBRT as low as 32 s (Fig 1). No H_2S was detected in the effluent stream regardless of the bioreactor configuration tested and the EBRT employed, which is in agreement with the reasonable good biodegradability reported in literature of this odorant. Butanone REs remained always over 97% in the BF, being slightly higher in the AS system (>98%). Conversely, the BF exhibited a better performance for toluene removal than the AS system, with REs exceeding 98% and 95%, respectively, at all EBRT tested. The comparable REs obtained for butanone and toluene despite the higher hydrophobicity of the latter suggest that no mass transfer limitations occurred for these odorous compounds. On the other hand, very low REs were recorded for alpha-pinene (only an EBRT of 32s was assessed), which remained at 7.3% and 6.8% in the BF and the AS, respectively, after two days of operation. Alpha-pinene biodegradation was likely limited by its mass transfer to the microbial community based on its high Henry law constant (low concentration gradient available for mass transfer).

No significant variation on H_2S, butanone and toluene RE was observed with daily glucose addition, ruling out the hypothesis of a reduced VOC-biodegradation in the presence of an easily degradable carbon source.

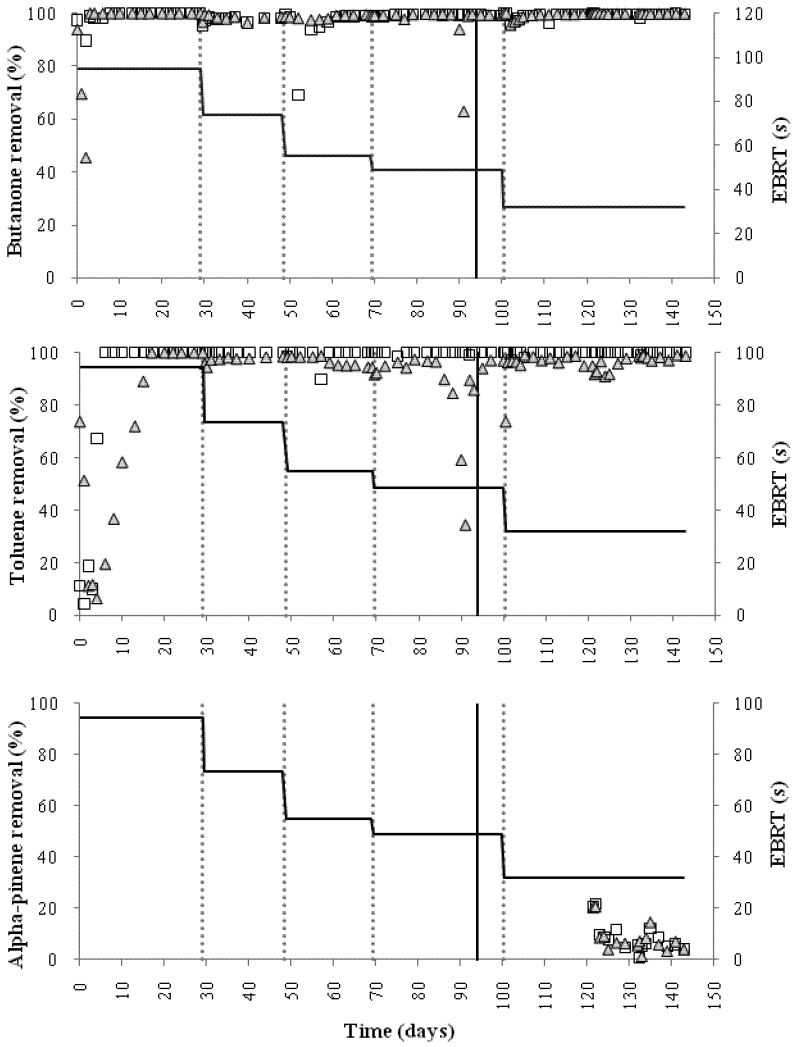

Fig. 1. *Time course of butanone (a), toluene (b) and alpha-pinene (c) REs in the BF (□) and the AS (▲). The continuous line represents the EBRTs, the vertical dotted lines represent the operation at different EBRT while the vertical line represents the beginning of AS operation at 25 days of sludge retention time.*

Both systems also presented reasonably efficient transient performance following the step decreases in EBRT, but in some cases a maximum of 10 days were required to reach a new steady state.

The longitudinal profiles along the BF height showed that REs higher than 98% and 94% for toluene and butanone, respectively, were achieved within the first 40 cm of the packing material (approximately 30% of the bed height) after day 29 of operation. Odorant RE in this first module increased throughout the experimentation period (Fig. 2). Likewise, H_2S concentration was already totally removed at this sampling point from the first day of operation. Complete removal of pollutants in the first part of BF systems has already been reported by other authors, although the time course of odorant removal profiles had never been assessed (Cabrol et al. 2008).

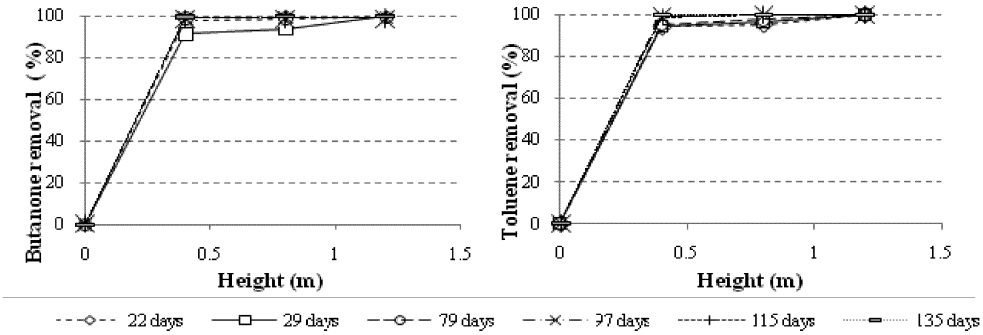

Fig. 2 *Time course of removal efficiencies of butanone (a) and toluene (b) at different biofilter bed heights and EBRTs*

Due to the low concentration of VOCs fed to the bioreactors, the amount of CO_2 produced by microorganisms did not differ significantly from the inlet concentration. Slightly higher values were obtained in the BF than in the AS before glucose addition, probably due to the partial and slow degradation of organic carbon present in the compost.

Biomass concentration in the AS liquor steadily decreased during the first 84 days of operation and dropped sharply from day 85 to day 91 to 0.12 g DW L^{-1}. At this point most of the biomass was aggregated at the bottom of the reactor. Following glucose addition, a rapid biomass resuspension and growth occurred, reaching a steady value of 2.4 g DW L^{-1} by day 93. Similarly, the specific ATP content increased noticeably following glucose addition from $5.0 \cdot 10^{-9}$ mol ATP (g biomass)$^{-1}$ to $3.7 \cdot 10^{-8}$ mol ATP (g biomass)$^{-1}$. Therefore, the presence of an easily biodegradable carbon source appears to be a requirement for a successful odour removal in terms of microbial stability.

Pressure drop throughout the BF bed increased when decreasing the EBRT from 8 cm H_2O at 94 s to 33 cm H_2O at 32 s. The gradual compaction of the packing material and the accumulation of biomass as biofilm could have also contributed to these high values. Finally, the packing material of the BF lost its buffer capacity after 80 days operation and a rapid decrease on the pH was observed. Nevertheless, the removal efficiencies for the tested compounds remained unmodified despite the low pH values of the BF leachate (around 1.3), suggesting an acclimation of the microbial population.

4. Conclusions

The results obtained in this study confirmed that AS diffusion systems are a competitive biotechnology for odour treatment, with REs comparable to those recorded in the BF for H_2S, butanone and the moderately soluble VOC toluene (> 95%). This study provided new data concerning the VOC elimination potential of AS diffusion systems at the low inlet odorant concentrations found in WWTP emissions. Besides, it has been demonstrated that the continuous supply of an easily biodegradable carbon source in the AS aeration tanks did not affect the removal of odorous compounds but rather contributed to an enhanced process stability. In brief, the difficulties in the control of biofilter operational parameters such as pH and moisture content, and the high pressure drop values throughout the bed, further encouraged the use of AS systems versus media-based biotechnologies. However, more research is needed to assess the robustness of AS systems for the treatment hydrophobic odorants at low concentrations.

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